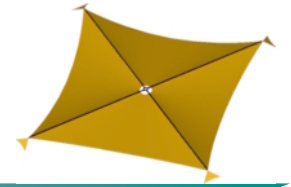




**JPL**



*ISP Solar Sail*



# TESTING OF A 4-QUADRANT SOLAR SAIL



**David “Leo” Lichodziejewski  
Billy Derbès  
Gordon Veal**



**Dr. Kara Slade  
Troy Mann  
David Sleight  
Richard Pappa**

**NASA Earth-Sun System Technology Conference 2005**

**Maryland**

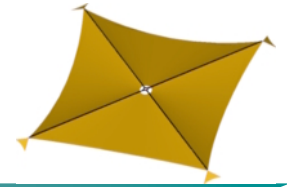
**June 28-30, 2005**



**JPL**



# *ISP Solar Sail*



## **AGENDA**

L'GARDE, INC.

- Design Overview
- Deployment Simulation
- Maneuver Simulations
- Structural Concept
- 20m 4-Quadrant System
- Vibration Testing
- Ascent Vent Testing
- 20m System Ambient Deployment
- Program Overview



**Deployed 20m Solar Sail**

# 1AU Solar Sail Baseline

## Baseline Mission

- Solar sentinel
- Sub L1 diamond
- Flexible mission set

## Sail Subsystem

- 10,000m<sup>2</sup> area
- 4.8 g/m<sup>2</sup> areal Density
- 2μm Mylar sail
- Inflatable deployment
- Sub Tg rigidization
- Vane 3-axis ACS
- Scalable architecture
- **47.4 kg flight mass**

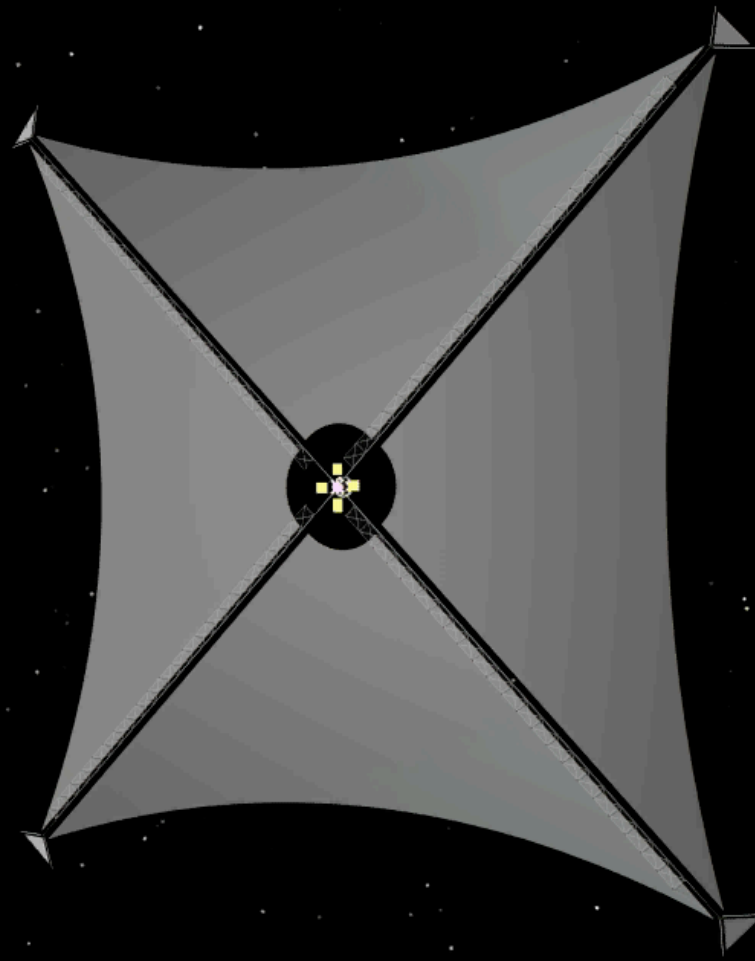
## L1 Baseline Design

- 50.0 kg payload
- 43.3 kg spacecraft
- 14.1 g/m<sup>2</sup> sail loading
- 0.58 mm/s<sup>2</sup> acceleration
- **140.7 kg flight mass**

## Space Segment

(Sailcraft + Jettisoned Equipme

- 232.9 kg launch mass
- 1.7 m<sup>3</sup> stowed volume
- 92.2 kg jettisoned

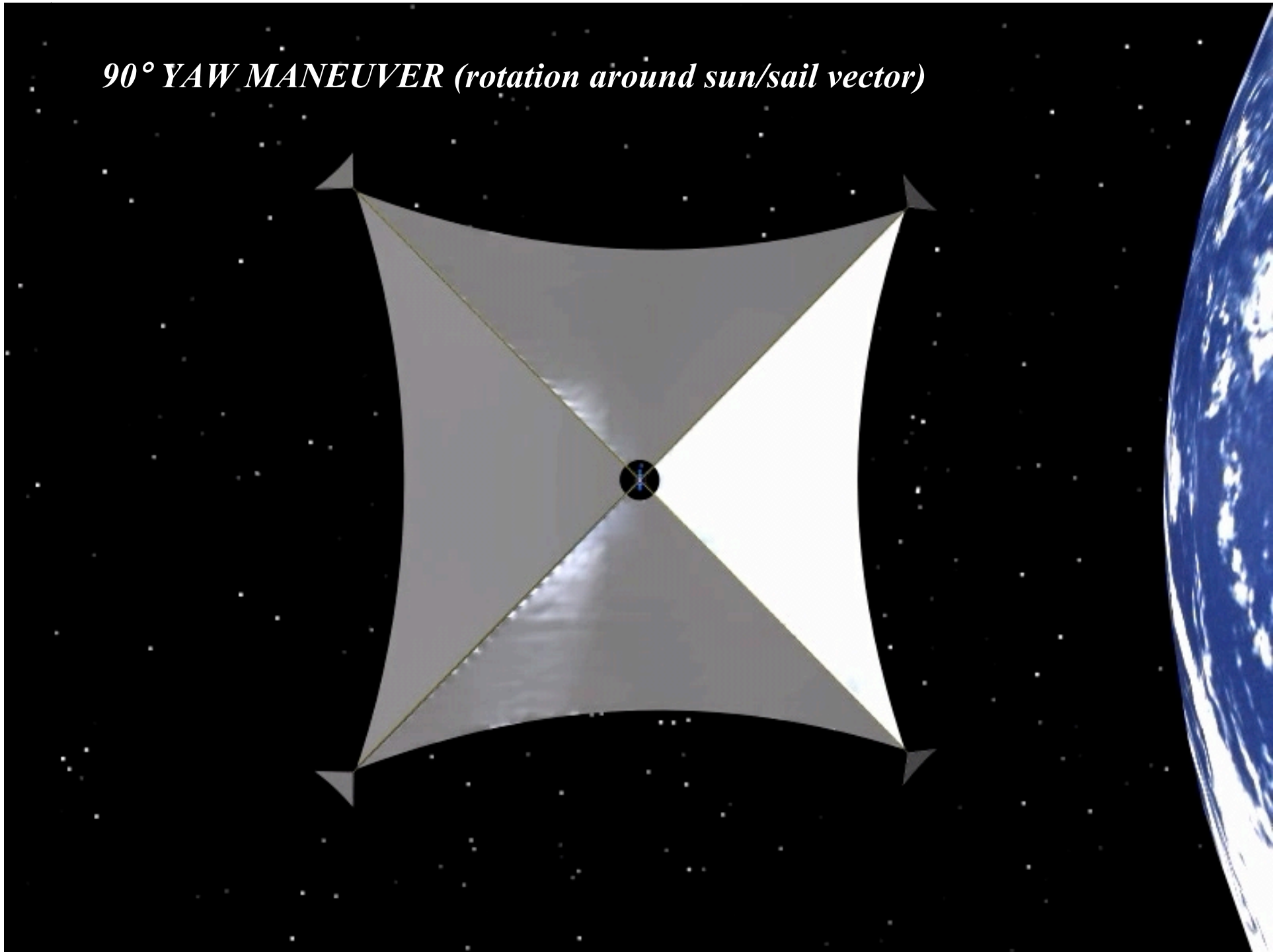




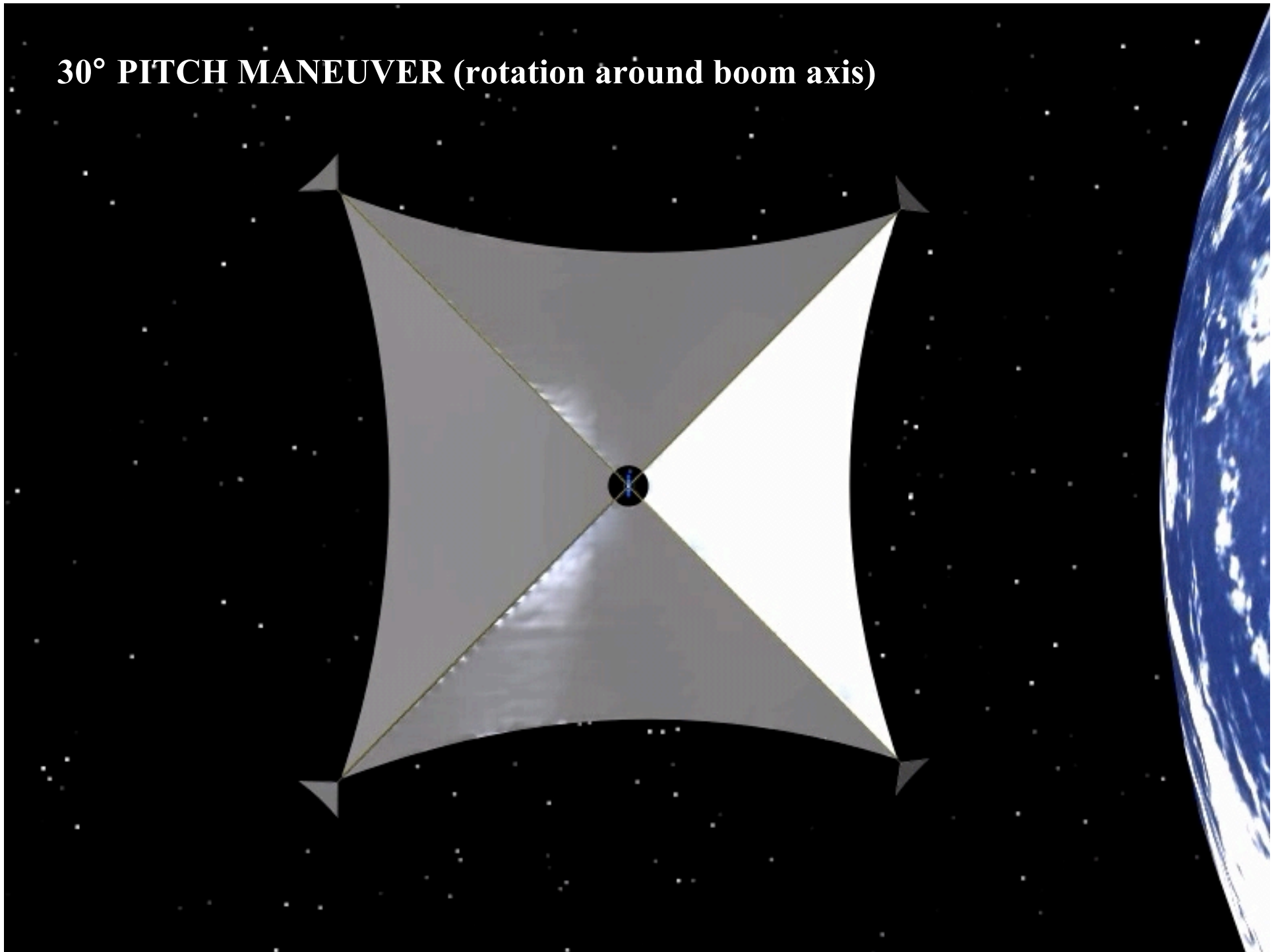
## **Deployment Animation**

- Carrier lid release
- Vane deployment
- Boom/sail deployment
- Carrier separation

*90° YAW MANEUVER (rotation around sun/sail vector)*



**30° PITCH MANEUVER (rotation around boom axis)**



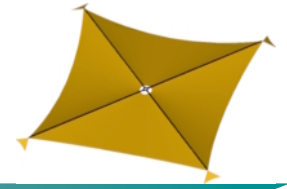




# ISP Solar Sail

## "PROA" BEAM STRUCTURE

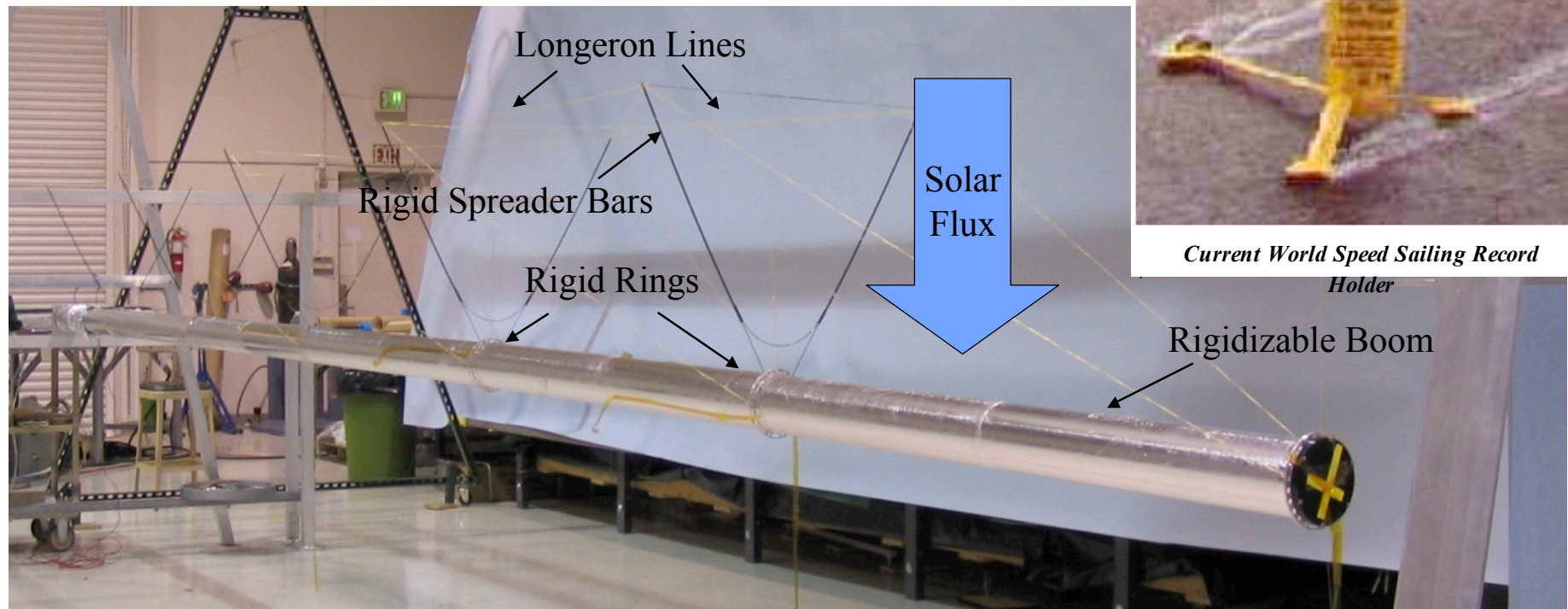
L'GARDE, INC.



- Proa sailboat is stressed for load in one direction for efficiency
- Our sail structure is stressed for solar loading in one direction for mass efficiency
- Truss system comprised of mostly tension elements, minimal rigid components
- Highly mass efficient,  $\sim 36\text{g/m}$  linear density



*Current World Speed Sailing Record Holder*



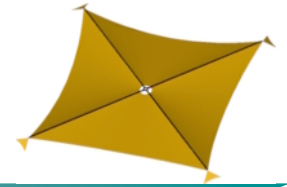
**Deployed 7.4m Solar Sail Beam**



# ISP Solar Sail

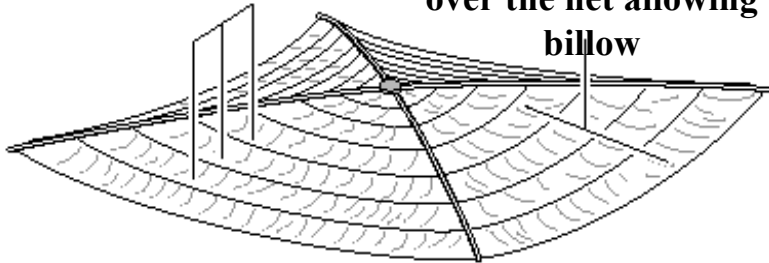
## NET/MEMBRANE SAIL DESIGN

L'GARDE, INC.



Chords are suspended  
from the boom rings

Sail material is laid  
over the net allowing  
billow



**Net/Membrane Sail Schematic**



**10m Sail Quadrant**

### Net Membrane

- Sail is supported by a high modulus, low CTE net, additional membrane material allows thermal compliance
- Sail properties effect local billow between net members only, global sail shape is stable

### Advantages

- Net defines the overall sail shape, not the membrane
- Stability and geometry of the sail is effectively decoupled from membrane properties
- Sail shape, and hence sailcraft stability and performance, is predictable and stable
- No high local stress concentrations in the sail, loads are transferred though the net, not the membrane
- Very scalable, larger net/membrane sails simply add additional net elements to control overall shape





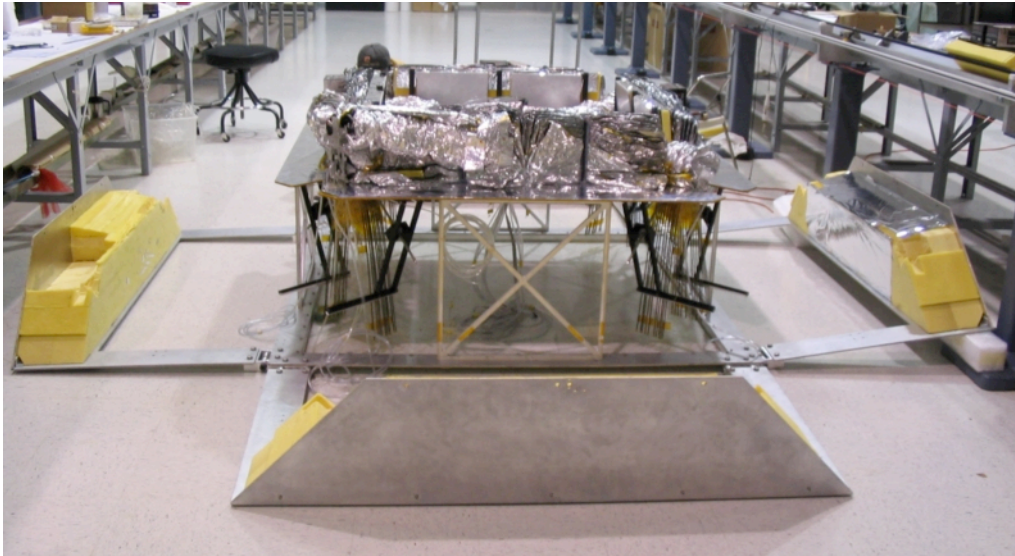
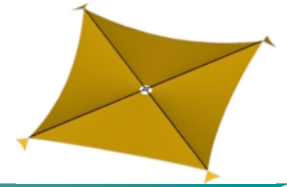
**JPL**



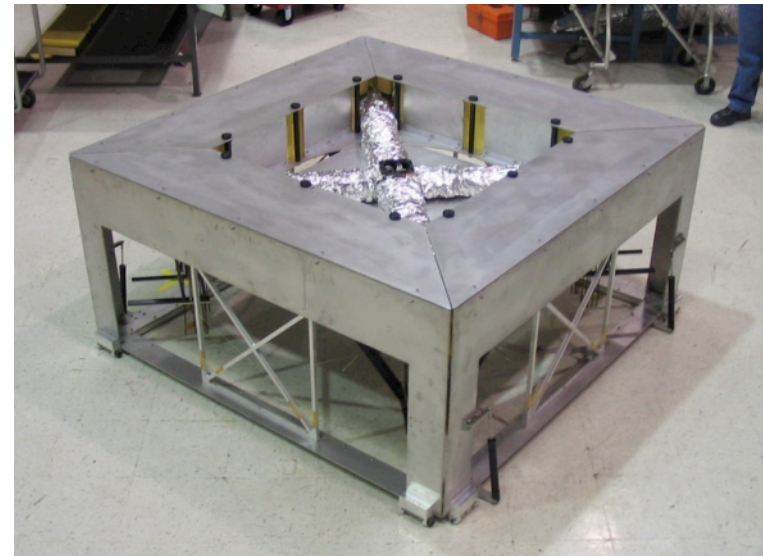
# *ISP Solar Sail*

## **20M SOLAR SAIL SYSTEM**

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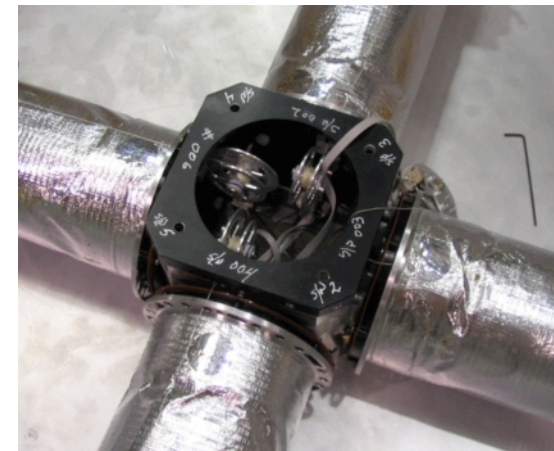


**20m ATS System (doors open)**

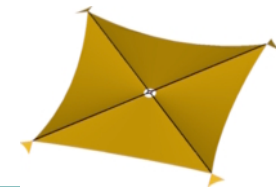


**Stowed 20m ATS System**

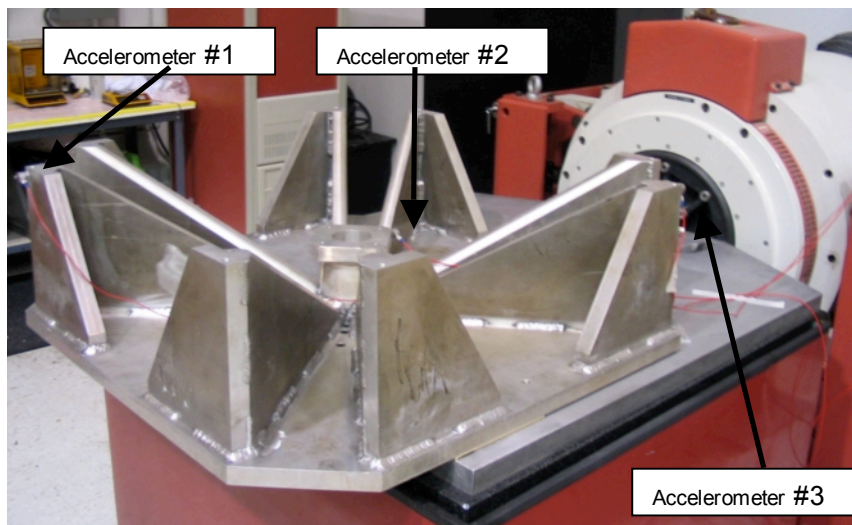
- Flight-like canister fabricated of aluminum honey-comb
- Features functional doors
- Incorporates flight-like launch restrain for beams and sails
- Canister designed for the 100m configuration
- Foam simulates the stowed 100m sail
- Canister hub houses extensometers to measure boom extension
- Canister can be manually disengaged from sailcraft to simulate canister jettison



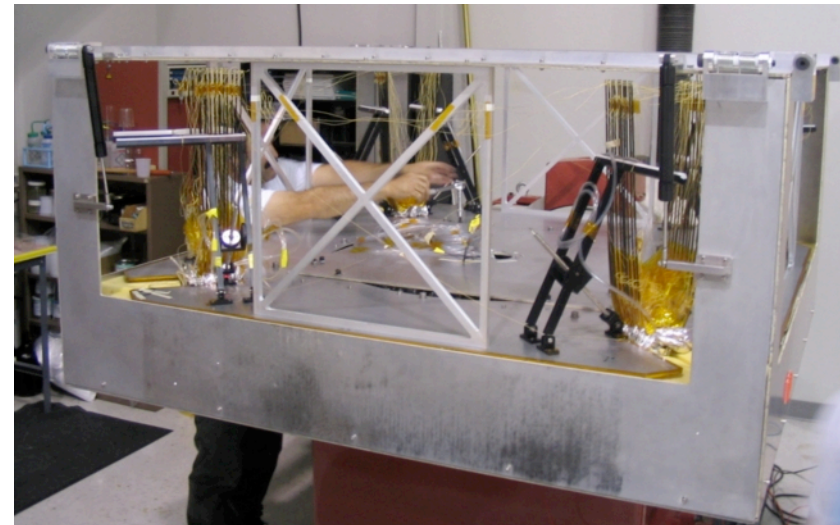
**Extensometers**



## LAUNCH VIBRATION SETUP

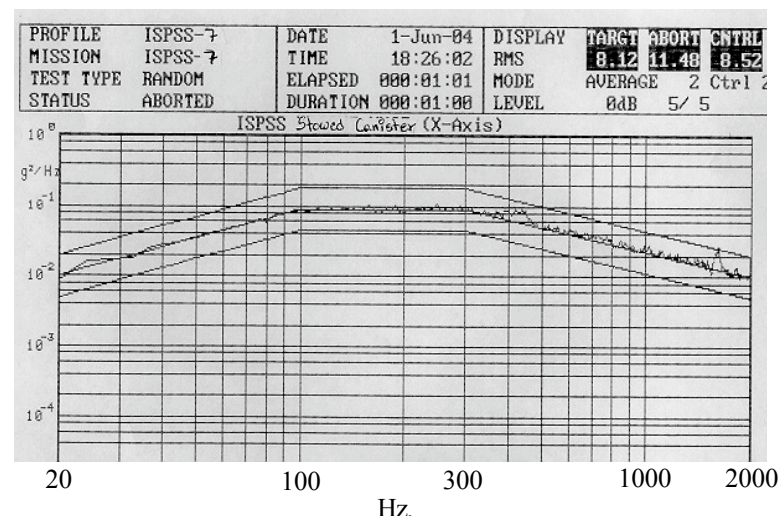


Accelerometer Locations



Vibration Test Setup

- X,Y, and Z axis launch vibration testing went very well
- Fairly violent shaking had no discernable effect on canister or stowed configuration
- Line management remained in place
- Test very successful
- Subsequent ambient deployment validates compliance



Applied Vibration Levels (X-Axis)

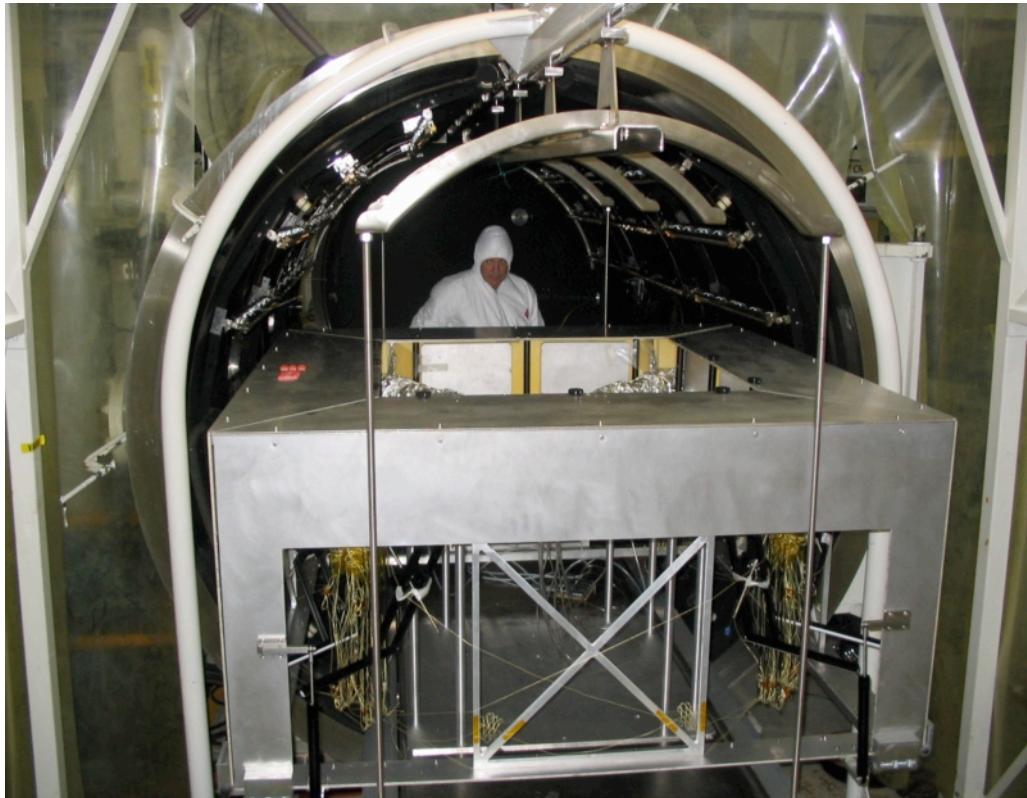
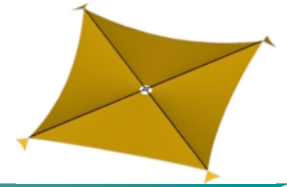




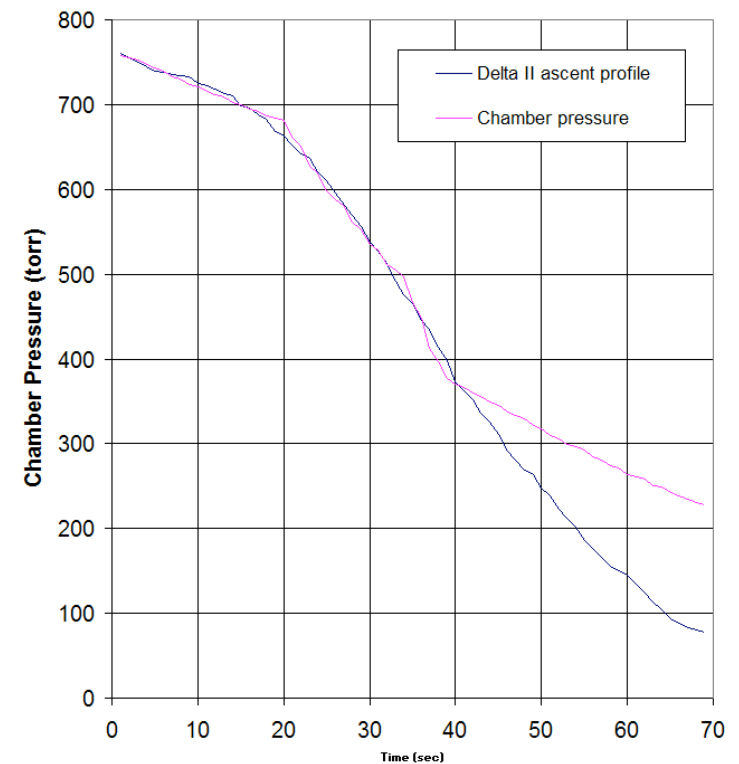
# ISP Solar Sail

## ASCENT VENT TEST

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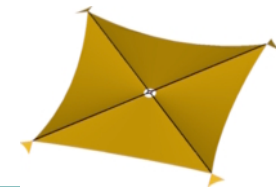


**LaRC Thermal Vacuum Chamber**



**Tested Pressure Profile**

- Ascent vent test conducted at LaRC's 2m\*4.5m vacuum chamber
- Vent profile similar to Delta 2 launch profile
- Pressures were monitored in the beams and mandrels and never exceeded 0.7 psi during venting
- No adverse effect on canister, beams, or sails noted during ascent venting



**Deployed 20m Solar Sail in L'Garde's High Bay**

- Successful deployment after launch vibration and ascent venting validates compatibility with launch environment
- Configuration sent to Plum Brook for thermal vacuum testing ...





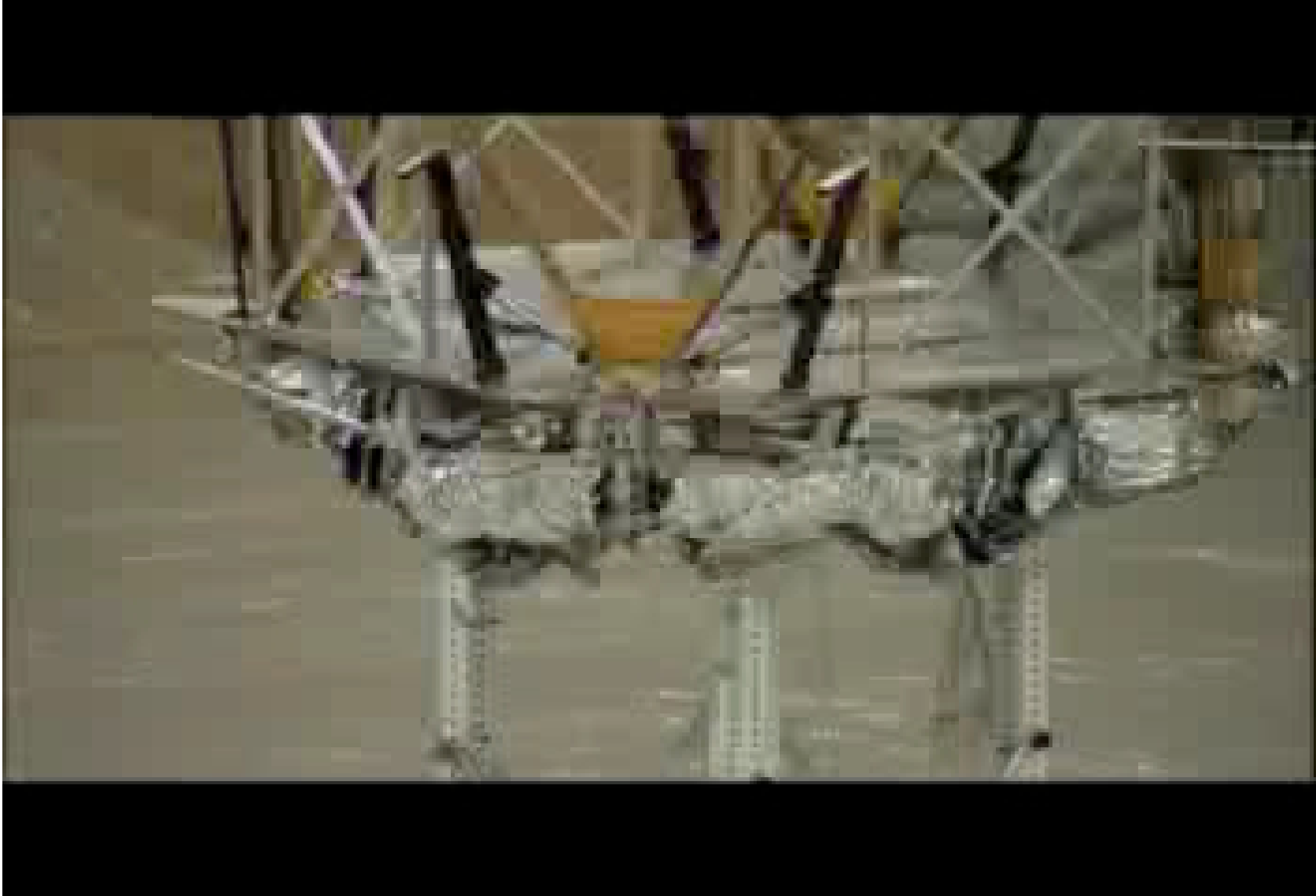
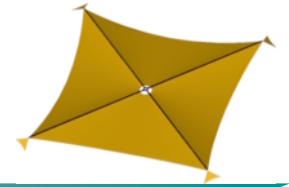
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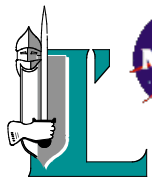
# *ISP Solar Sail*

## *20M AMBIENT DEPLOYMENT AT L'GARDE*

L'GARDE, INC.



*ISP Solar Sail*



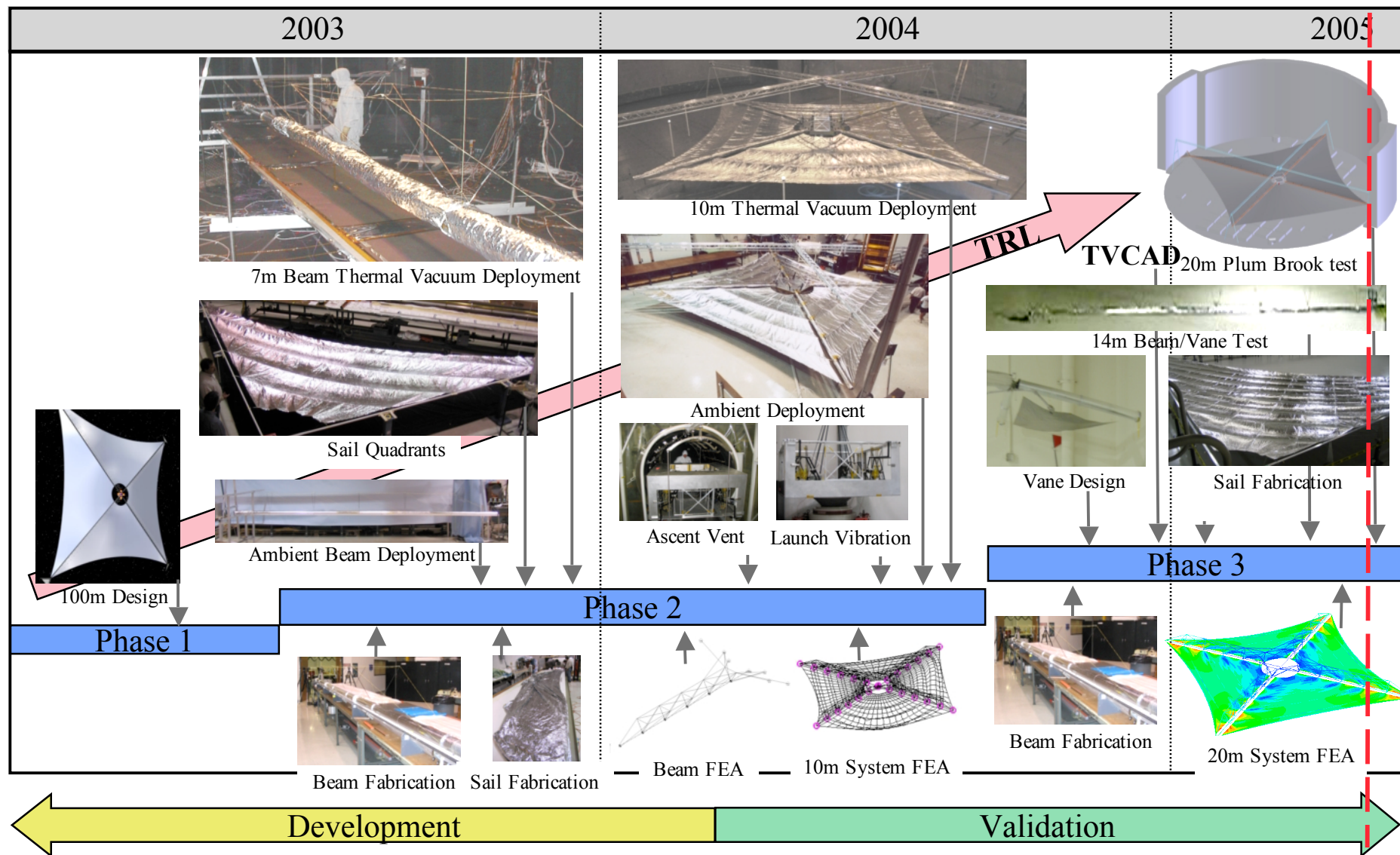
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# ISP Solar Sail

## PROGRAM TIMELINE

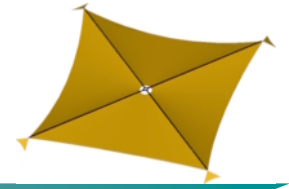
L'GARDE, INC.



ISP Solar Sail



# ISP Solar Sail



## SUMMARY

L'GARDE, INC.

### Design

- Meets L1 mission requirements – applicable to other NASA missions
- Low mass – striped sail architecture, “proa” structure
- Predictable sail shape – net/membrane configuration
- Scalable – striped sail architecture, conical stowage and deployment
- Controllable – vane control

### Testing

- Launch environment tests – stowed structure compatible with the launch environment
- Successful 10m system rough vacuum deployment test – validates deployment controllability
- Thermal vacuum structural tests – validates sub  $t_g$  rigidization and structural safety factors
- Static and dynamics testing – correlates with FEA
- **System is >TRL 5 and rising**

### Phase 3

- 20m configuration is as we speak being tested at Plum Brook
- Excellent opportunity to significantly advance solar sail technology
- Bringing this technology closer to flight!

*Much appreciation to Sandy Montgomery, Roy Young, and ISP Solar Sail team for great support!*